Population structure and growth of the fern *Rumohra adiantiformis* in relation to frond harvesting in the southern Cape forests

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Demography, phenology and experimental harvesting of the fern *Rumohra adiantiformis* (G. Forst.) Ching were studied as a basis of sustained commercial frond harvesting from indigenous forest. The fern grows densely and produces large fronds on moist, well-drained sites. Numbers of frond buds peak during spring, and mature utilizable fronds in late summer. Growth rates for frond development stages varied with season. The period from the bud stage to mature utilizable fronds averaged 16 weeks. The mature stage lasted 10–18 weeks during summer. Picking of all mature fronds on a 22-week cycle over 3 years reduced frond size to 51% of the controls and on a 4,3-week cycle to 24%. Density of buds and mature fronds was significantly reduced by picking. Reduced frond size and density, and production of malformed fronds are attributed to depletion of the potassium and phosphorous reserves in the plant. Decreased harvest intensity, longer harvest cycle, improved monitoring and future research are recommended for better resource conservation. Guidelines are provided for cultivation of the fern.

Demografie, fenologie en eksperimentele benutting van die varing *Rumohra adiantiformis* (G. Forst.) Ching is bestudeer as basis vir standhoudende kommersiële varingbenutting uit inheemse woud. Die varing groei dig en vorm groot blare op vogtige, goed-gedreineerde groeiplekke. Die getal blaarknoppe bereik 'n piek gedurende die lente en volwasse blare 'n piek in die laatsomer. Groeitempo van die blaarontwikkelingstadia varieer volgens seisoen. Die gemiddelde periode vanaf die knopstadium totdat die blaar volwasse en benutbaar is, is 16 weke. Die volwasse stadium duur 10–18 weke in die somer. Die pluk van alle volwasse blare oor 3 jaar het met 'n 22-week-siklus die blaargrootte tot 51% van die kontrole verminder, en met 'n 4,3-week-siklus tot 24%. Digtheid van knoppe en volwasse blare is betekenisvol verminder deur benutting. Verminderde blaargrootte en -digtheid, en vorming van abnormale blare word toegeskryf aan 'n uitputting van die kalium- en fosfaatreserwes van die plant. Verlaagde plukintensiteit, 'n verlengde pluksiklus, verbeterde monitering en verdere navorsing word aanbeveel vir beter bewaring van die hulpbron. Riglyne word voorsien vir die kweek van die varing.

Keywords: Forest product, growth rate, phenology, population structure, pteridophyte

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Introduction

Timber has always been the main product harvested from the southern Cape indigenous forests. Recently the seven-weeks fern [*Rumohra adiantiformis* (G. Forst.) Ching], also known as Knysna fern or American leather fern, became known as a useful plant. It is used extensively in the florist trade for greenery, both locally and abroad. The mature fronds can last for several weeks without wilting. Demand in South Africa is particularly high during the holiday and festive seasons. Overseas the demand is high during the Northern Hemisphere winter.

The fern is a proclaimed protected species (Cape Provincial Ordinance no. 19 of 1974, and Government Notice no. R917 of 1966), so that it may not be harvested on state forest land, and harvesting on private land is controlled through a permit system. Licensed growers could not satisfy the increasing demand for fern fronds, which resulted in illegal exploitation on state forest land.

During 1982, state forest land was released for harvesting of fern fronds for the European market. Tenders were invited for fern harvesting during 1 year on a relatively small area, i.e. 4 000 ha forest in the Harkerville–Kaffirkop area (Figure 1). The next year the tender was renewed for a further 2 years and over a total area of 7 000 ha (including the Diepwalle and Gouna forests). This was based on the premise that, in order to protect his product, the contractor would control illegal picking on a larger area. Furthermore, controlled utilization of the fern would add to the intrinsic value of private forests and indirectly contribute to their conservation (Geldenhuys 1983).

R. adiantiformis is a polymorphic terrestrial fern which is distributed widely in Australasia, South and Central America, southern Africa and some Indian Ocean islands. In southern Africa it occurs in forests extending from the south-western Cape, through Transkei and Natal and to the Transvaal mistbelt forests along the escarpment. It is common in moist forest but also occurs as a chasmophyte amongst boulders and rocks and occasionally as an epiphyte on trees (Jacobsen 1983; Schelpe & Anthony 1986). It is most abundant in the southern Cape where it grows from almost sea level in coastal dry and scrub forest, through forests on the coastal platform at *c.* 240 m, to montane forests at *c.* 1 000 m altitude. It is often associated with *Ocotea bullata* and *Platylophus trifoliatus* trees growing on podzols.

Fronds arise from a relatively short, unbranched rhizome up to 25 mm in diameter, and grow to a maximum height of 1,5 m in semi-dense forest on moist, well-drained sites. The plant is similar to bracken (*Pteridium aquilinum*) in the arrangement of fronds on the rhizome, though bracken has a deep-rooting, long-branching rhizome (Watt 1940).

Only fully mature, hardened fronds, without necroses or other blemishes, are utilized for the florist trade. Immature fronds wilt when picked and have no value. Frond size, form and colour are important criteria of quality.

When controlled harvesting started, we implemented research at three levels to advise the managers. We used (1) demographic studies to answer questions such as: How is the fern population in a site distributed and structured? Does the proportion of frond stages vary seasonally? What is the frond growth rate and how does it vary seasonally? We used (2) active management studies to reply to questions such as: At what harvest frequency can we sustain production? How does excessive harvesting affect the quality of the fern? What variables should we measure during monitoring to detect adverse effects timeously? With the assistance of managers we (3) implemented extensive monitoring in the contract area to get answers to the following: Are the results obtained from the study site related to the effects of harvesting in the contract area? Does the contractor harvest the fern within the stated limits? The contractor conducted additional research on the ecology of the fern (Milton & Moll 1987). We report here on results from our demographic and active management studies.

Study areas

We studied the fern in the Groenkop Forest study site (22° 33′S 33° 56′E, 300 m a.s.l.) on Witfontein State Forest (Figure 1). The site, with generally southerly aspect, occurs where the base of a foothill of the Outeniqua mountains joins the coastal platform. In the north the slope is 17° and the parent material a colluvium of variable depth. South of the slope break the slope is 5° and a series of well-developed podzols overlie the saprolite of Table Mountain sandstone boulders. Water drains excessively on both sides of the slope break, but seems to accumulate in the slope break (T.A. Robertson, pers. comm. 1985). The Walter climograph summarizes the principal features of the area (Figure 2). The forest is 21 m tall and consists of a mixture of the typical evergreen tree species of forests on the coastal platform (Geldenhuys & van Laar 1980). Tree falls frequently occur on the footslope. The understorey is dominated by a dense *Rumohra* stand which in the southern portion gradually changes to a tall, dense shrub layer of *Tri chocladus crinitus*, with no *Rumohra*.

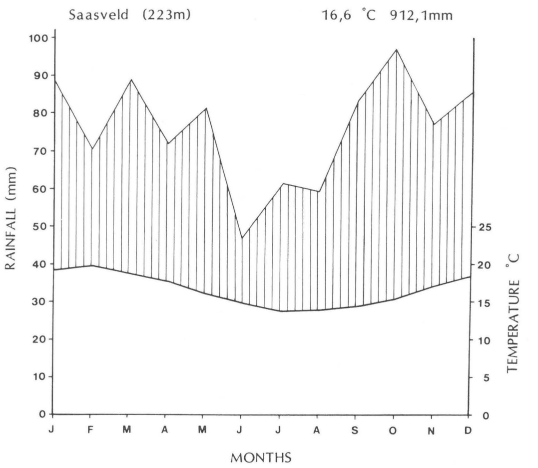

Figure 2 Walter climograph for the Saasveld Weather Station close to the study site, based on weather data for the period 1974–1985 (Walter 1979).

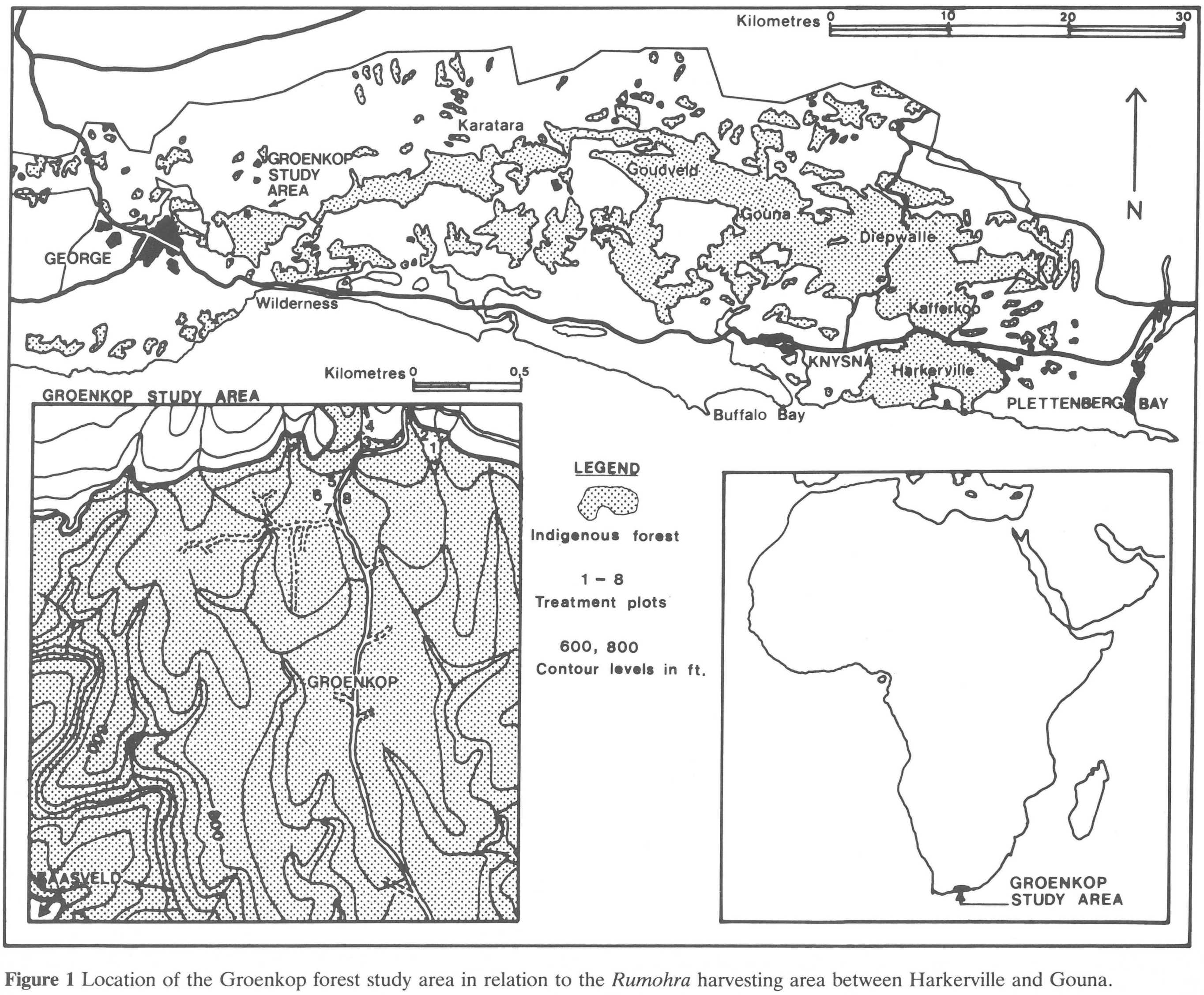

Figure 1 Location of the Groenkop forest study area in relation to the *Rumohra* harvesting area between Harkerville and Gouna.

Methods

Population structure

In this study we describe population structure in terms of the variation in frond density at a particular site, the relative numbers of fronds in different development stages (Figure 3), and the height–class distribution of fronds. We sampled the study area during January 1985 with three parallel transects orientated east–west, and recorded data on circular plots of 0,5-m radius located 5 m apart on the transects. On each plot we counted the number of fronds in each stage. During June 1985 we determined the height range of fronds on 10 plots along each of the lines. We counted the fronds, and measured stalk length (as index of frond height), width, length and surface area (frond size) of each lamina, of each frond development stage.

Bud initiation, frond growth rate and frond size

We tagged 275 individual fronds to follow their development from bud appearance to death. Every month, for a full year, we marked a new line transect at random through the fern stands, tagged 20–30 buds touching the line, and every fortnight, recorded the following: frond stage, stalk length, and length and width of lamina. We determined lamina surface area for a number of fronds with a Li-Cor 3100 leaf area meter. During February 1983 twice the usual number of buds were marked due to high bud mortality during January 1983. During April 1983 few buds developed. During August 1983 no buds were marked due to an oversight.

We calculated frond growth rate as the average length of time a frond remained in a particular development stage. However, some buds had grown for some time when we marked them. Bud stalk length at the time of marking showed a significant inverse linear relationship to the observed period in the bud stage. We used this relationship to calculate the duration of the bud stage.

Treatment plots

We selected eight blocks to represent a gradient from dense to sparse fern stands. Each block was subdivided into three plots of 3 × 3 m, with an inner measurement plot of 2 × 2 m. The following treatments were applied to the plots at random:

(1) Control: no picking.
(2) Five-monthly (22 weeks) picking of all utilizable fronds.
(3) Monthly (4, 3 weeks) picking of all utilizable fronds.

We applied treatments from July 1982 to August 1985. Buds, and young, mature and overmature fronds were counted monthly. Due to the long duration of frond stages and the fact that fronds were not tagged, we counted some fronds more than once. We therefore corrected bud counts for each month from the growth rate of buds of the previous month, using the following equation:

$$N_{cc} = N_c - [N_p - (4{,}3N_p/P_p)]$$

where

N_{cc} = corrected count of buds for current month,
N_c = actual count of buds for current month,
N_p = actual count of buds for previous month,
P_p = period in weeks of bud stage for previous month (Figure 6),
4,3 = constant for length of month in weeks.

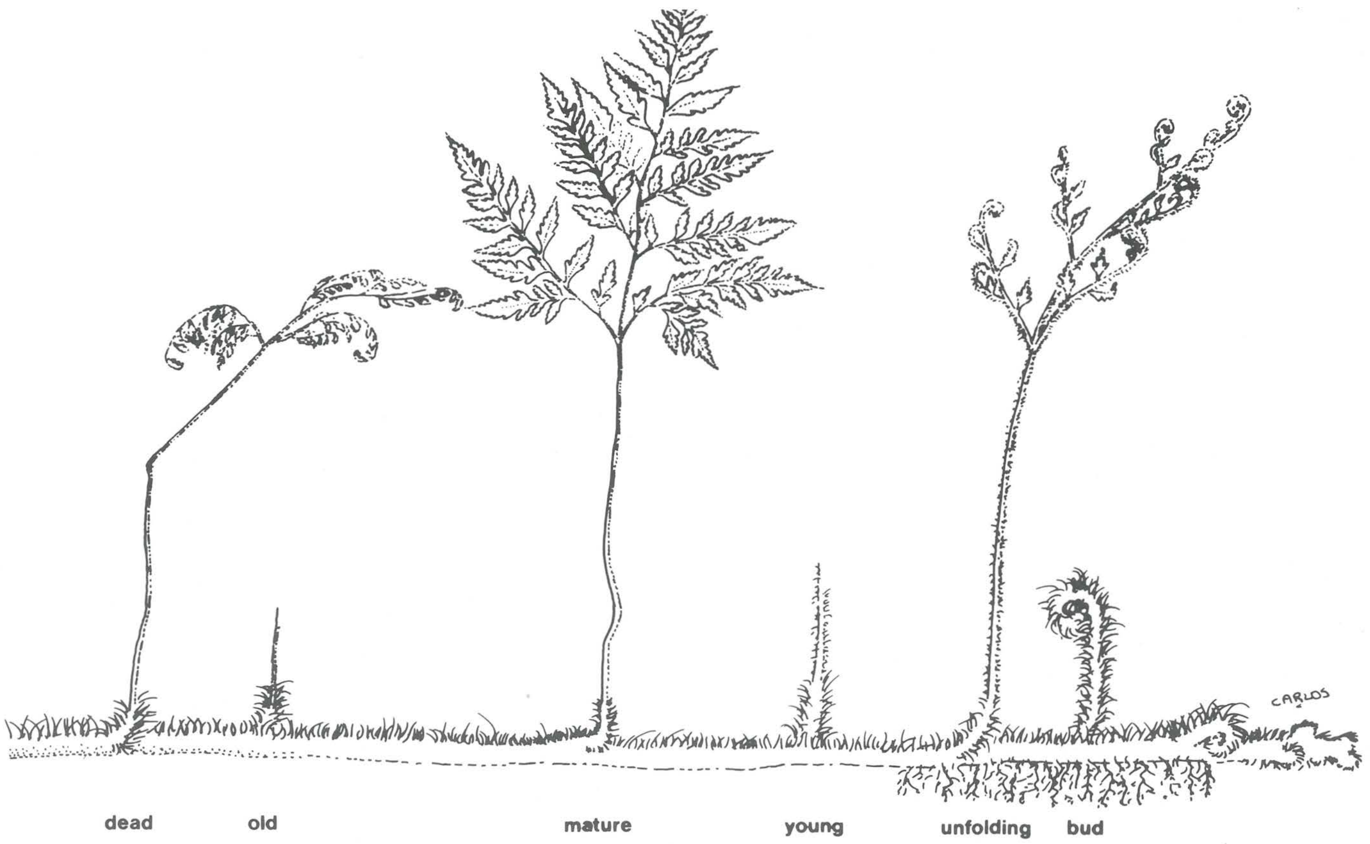

Figure 3 Frond development stages of *Rumohra adiantiformis*. The form of young, mature and old fronds is similar. Bud stage: coiled buds covered with reddish-brown, hairpointed scales, protrude above the soil and grow to the mature height before unfolding. Unfolding stage: the frond lamina and leaflets unfold, become pale green and enlarge. Young stage: the frond develops fully, remains soft, feels oily and is bright green. Mature stage: the frond is dark green and leathery. Old stage: yellow necroses and damage by tree litter and insects cover more than 5% of the lamina area and the frond becomes moribund. Dead stage: the entire frond is dead, but often remains standing for a considerable period due to the support from surrounding fronds.

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During May 1985 we measured the length and width of the lamina of each mature frond in the plots to determine the effect of treatment on frond size.

Results

Population structure

Population structure varied between the three transects

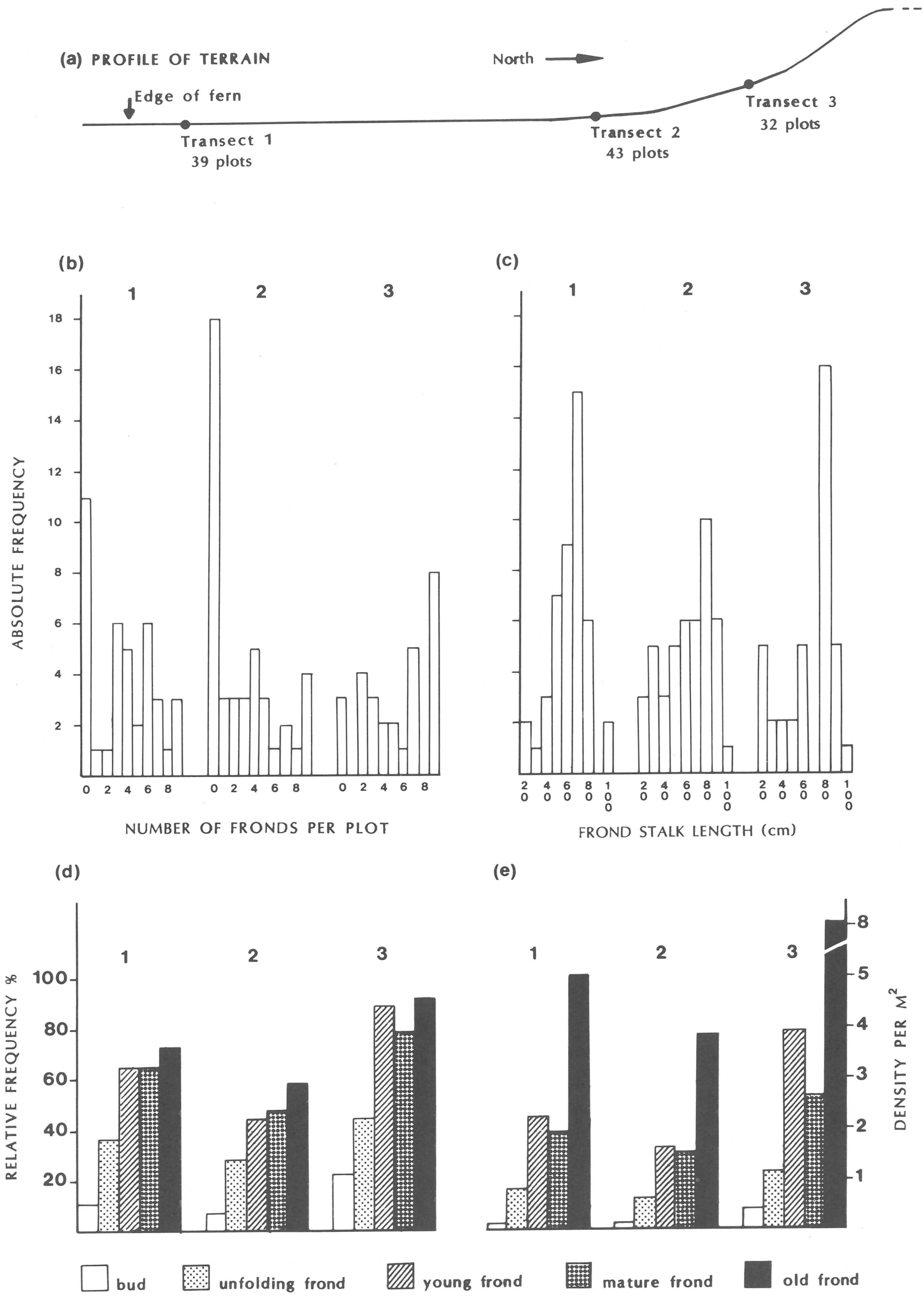

Figure 4 Population structure of *Rumohra adiantiformis* (a) on three transects in the Groenkop forest study site; absolute frequency of (b) number of fronds per plot of 0,5 m radius and of (c) frond stalks of particular length; and (d) relative frequency and (e) density of fronds in particular development stages.

during January 1985 (Figure 4). The coefficient of skewness (Snedecor & Cochran 1967), a measure of dispersion of the fronds, was insignificant for transects on the lower plateau and footslope. This indicated a uniform distribution of fronds among the sample units in dense fern stands. On the slope break with relatively sparse fern, the sample showed a significant positive skewness ($P < 0{,}01$), i.e. indicating many empty plots and relatively dense clumps of fronds in many other plots.

Average frond density on the transect plots varied between 3,8 and 8,0 fronds m^{-2} (with coefficient of variation ranging between 62,5 and 118%). On the treatment plots, frond density ranged between 7,5 and 20,8 fronds m^{-2}. The densest fern stands occurred on the footslope under a relatively sparse tree stand of mostly tall trees, closed upper canopy and open middle and lower storeys. The relatively sparse fern stands on the slope break occurred under many large trees of *Platylophus trifoliatus* with a deep, dense crown. This site had a pit and mound microtopography (probably due to windfalls) and was relatively poorly drained.

The average ratio of frond stages was 0,2 buds, 0,8 young (including unfolding) fronds, 2,5 mature fronds and 2,0 old fronds m^{-2} for January 1985. The ratio of frond stages, however, changed with season. During June 1985, along the same transects, the average ratio was 0,6 buds, 0,3 young, 0,9 mature and 4,1 old fronds m^{-2}. Table 2 summarizes the changes over time in ratio of frond stages for the treatment plots.

Frond stalk length (frond height) averaged 0,69 m (range 0,32–1,06 m) on the lower plateau, 0,63 m (range 0,12–1,05 m) on the slope break, and 0,70 m (range 0,20–1,11 m) on the footslope (Figure 4c). Although fronds in a fern stand appear to be of uniform height, many relatively short fronds were present. In mature fronds the relationships between lamina length and the variables of stalk length, lamina width, and lamina surface area were highly significant ($P < 0{,}01$). Values for goodness of fit of 11 alternative nonlinear regression models were compared and the models giving the best fit are indicated (Figure 5). The high values for R^2 indicate that a large proportion of the variation in the dependent variables is explained by these regressions. Frond stalk length therefore provides a reliable estimate of frond size.

Phenology and frond growth rate

Bud initiation and frond growth rate varied seasonally (Figures 6 & 7; Table 1). Bud initiation increased sharply between May and July and reached a maximum between September and November. On average, height of buds when marked were smallest during November–December 1982 and May–July 1983. During other months most buds had grown to various heights (Figure 6a). The bud stage took on average 6,1 weeks (range 5,2–7,7 weeks) for October–March buds, increased to 13,9 weeks for April buds, and then decreased steadily to 4,5 weeks for September buds. The unfolding stage took 3,9 weeks (3,5–4,3 weeks), and the young stage 4,6 weeks (3,1–6,7 weeks) for October–March buds, increased to 5,8 (unfolding) and 5,1

Table 1 Seasonal variation in bud density and duration of frond stages of *Rumohra adiantiformis* in the Groenkop forest

Month for bud initiation	No. buds marked	Bud density[1] number m^{-2}	Period, weeks[2]: Bud to young stage	Mature stage	Total
October 1982	36	3,65	13,6	13,0	26,6
November	64	0,76	14,6	10,3	24,9
December	20	0,33	13,4	18,0	31,4
January 1983[3]		0,17			
February	40	0,14	15,3	16,6	31,9
March	20	0,02	16,0	6,8	22,8
April	15	0,003	24,8	7,5	32,3
May	20	0,13	20,7	7,1	27,8
June	20	0,47	18,2	7,6	25,8
July	20	0,80	12,9	12,2	25,1
August[3]		1,61			
September	40	3,19	8,5	15,2	23,7

[1]Calculated from treatment plot data
[2]Calculated from line data
[3]Line data not available

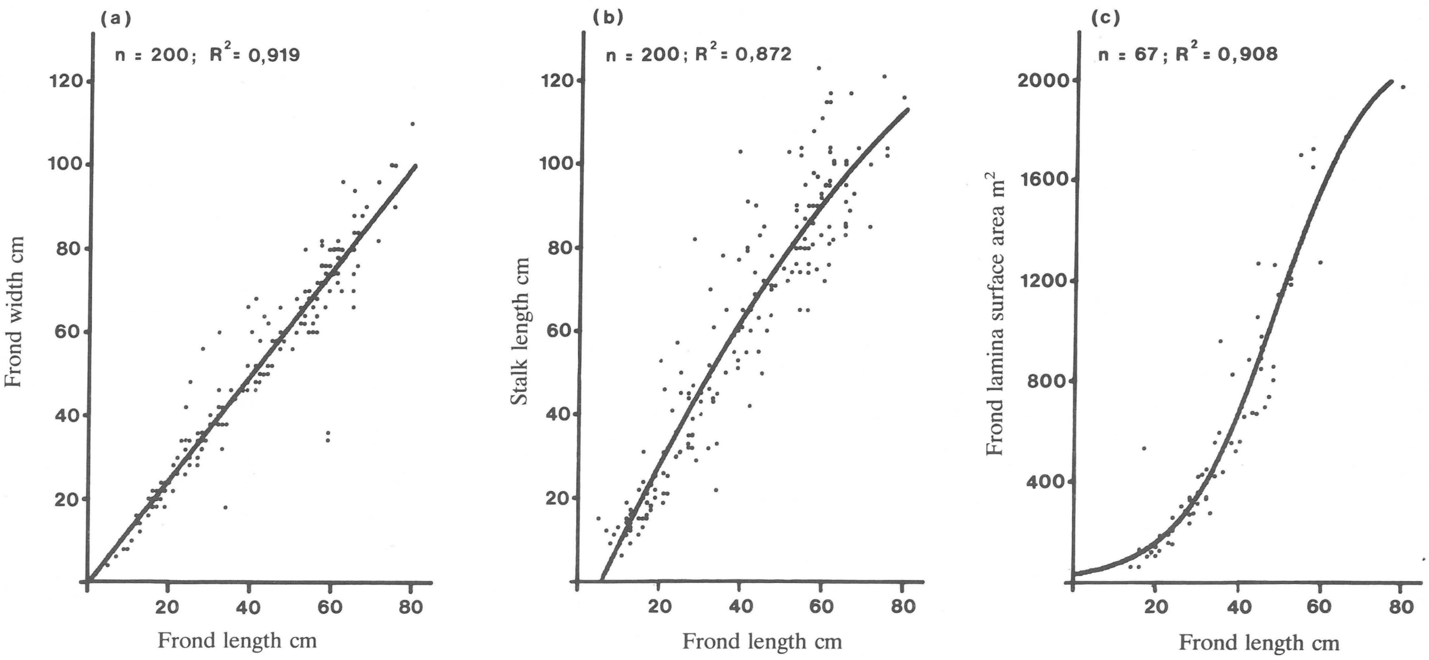

Figure 5 Frond lamina length of *Rumohra adiantiformis* in Groenkop forest in relation to (a) frond width, (b) stalk length and (c) surface area. The models which gave the best fit, i.e. highest R^2 value, are shown. These are (a) $Y=1{,}255X-0{,}516$; (b) $Y=-0{,}1293 + 2{,}2078X-0{,}007895X^2$; (c) $Y = 1/(0{,}0004618 + 0{,}03522e^{-0{,}08947X})$.

(young) weeks for April buds, and steadily decreased to 2,0 weeks for both stages for September buds. The entire immature stage averaged 15,3 weeks (range 8,5 weeks for September buds to 24,8 weeks for April buds). The mature stage took 11,1 weeks for October-November buds, increased to 17,3 weeks for December–February buds, sharply decreased to 7,3 weeks for March–June buds, and then sharply increased to 15,2 weeks for September buds. The total age of mature fronds varied considerably, i.e. 23–32 weeks. Old fronds remained alive for considerable

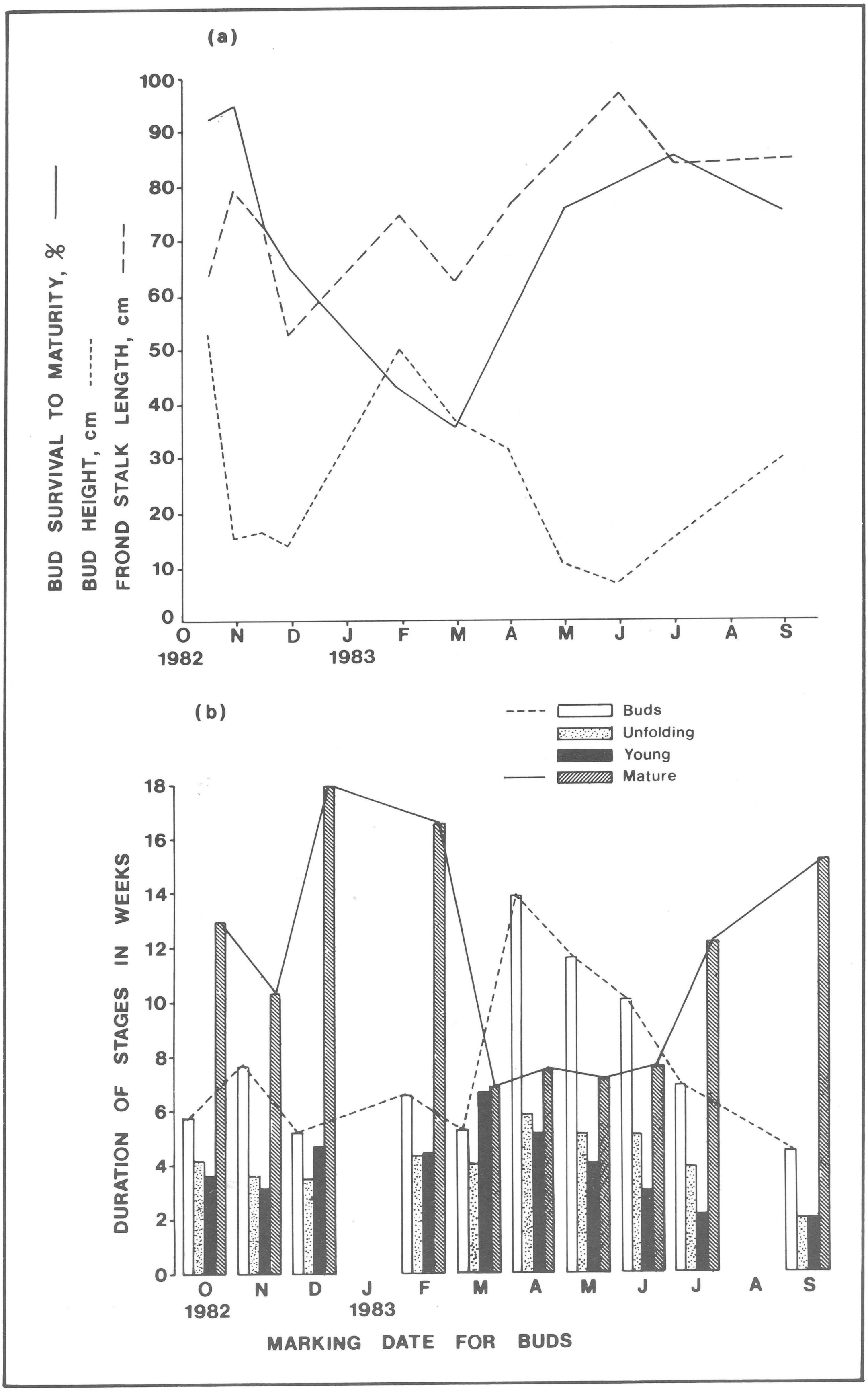

Figure 6 Seasonal trends in (a) bud survival and frond height, and (b) duration of the frond stages, for buds of *Rumohra adiantiformis* marked during different months in the Groenkop forest.

periods, on average 49,7 weeks (94 fronds), with longest period of 82 weeks.

Results from the studies on population structure and phenology are summarized in a model of seasonally changing fern population structure (Figure 8). Density of old fronds is not indicated due to their relatively long life span and irrelevance to harvest planning. Low densities of all frond stages occurred during April–June. During July–October many juvenile fronds and very few mature fronds occurred. From November mature fronds increased

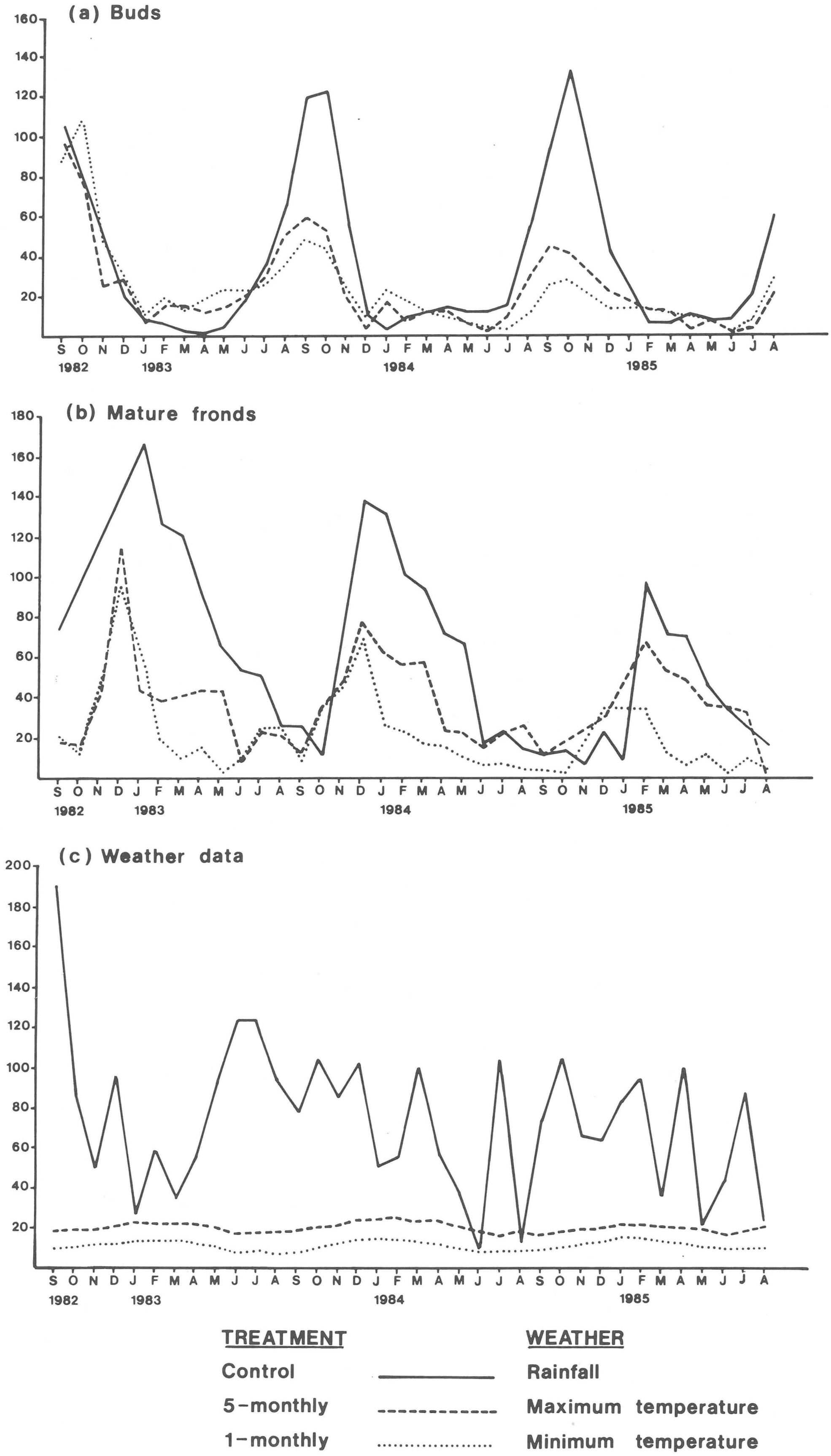

Figure 7 Seasonal variation in total number of (a) buds and (b) mature fronds of *Rumohra adiantiformis* in the Groenkop forest treatment plots, and (c) weather data collected at the nearby Saasveld weather station.

in proportion and dominated during January–March.

Buds appearing during winter and spring developed the longest stalks in mature fronds (Figure 6a). The strong positive correlation between stalk length and lamina length (Figure 5) therefore suggests that winter and spring buds produce larger fronds i.e. of better quality.

Bud mortality was high between December 1982 and March 1983 and mostly confined to that time of the year (Figure 6a). Usually the coiled bud with soft and fleshy tissue was removed. This was observed in the Knysna area too (S.J. Milton & R.M. Botha, pers. comm. 1985).

Treatment effects on population structure

Treatments changed the timing of bud initiation (Figure 7), and reduced the density of buds and mature fronds (Table 2) and the total number of fronds utilized (Table 3). We used February (mature frond peak) and October (bud peak) data to analyse treatment effects on population structure. Treatment differences during July were insignificant (Table 2; Figure 7). Bud density was markedly higher in October than in February in all treatments. In February differences between treatments were insignificant. In October, however, the controls had significantly higher densities than the treated plots with no differences between the two cycles or between years. During the bud flush after the first year of treatment (September 1983) control plots produced about twice as many buds as treated plots. This difference increased during October 1984. Treated plots, however, produced new buds over a longer period, probably as a result of shifts in the timing of a single major annual bud flush. This was particularly noticeable during February to May 1983, but the trend was of shorter duration after January 1984, and almost non-existent in 1985. The higher density of young fronds with increasing frequency of picking may be caused by the particular period selected for analysis. Mature frond densities were markedly higher in February than in October for controls, but less so between treated plots. Differences between the two cycles were significant. Numbers of mature fronds increased sharply from October, except for the third cycle when the increase occurred in February 1985. Note also the sharp increase in frond numbers before the peak and more gradual decrease thereafter. Treated plots show a similar pattern, but with lower peaks. Monthly removal of mature fronds, i.e. at intervals shorter than the mature stage of approximately 16 weeks, has a more marked effect on the curve than the 5-monthly cycle. Differences in old frond densities between February and October were small, but were more marked between treatments. Replications show significant differences in both buds and mature

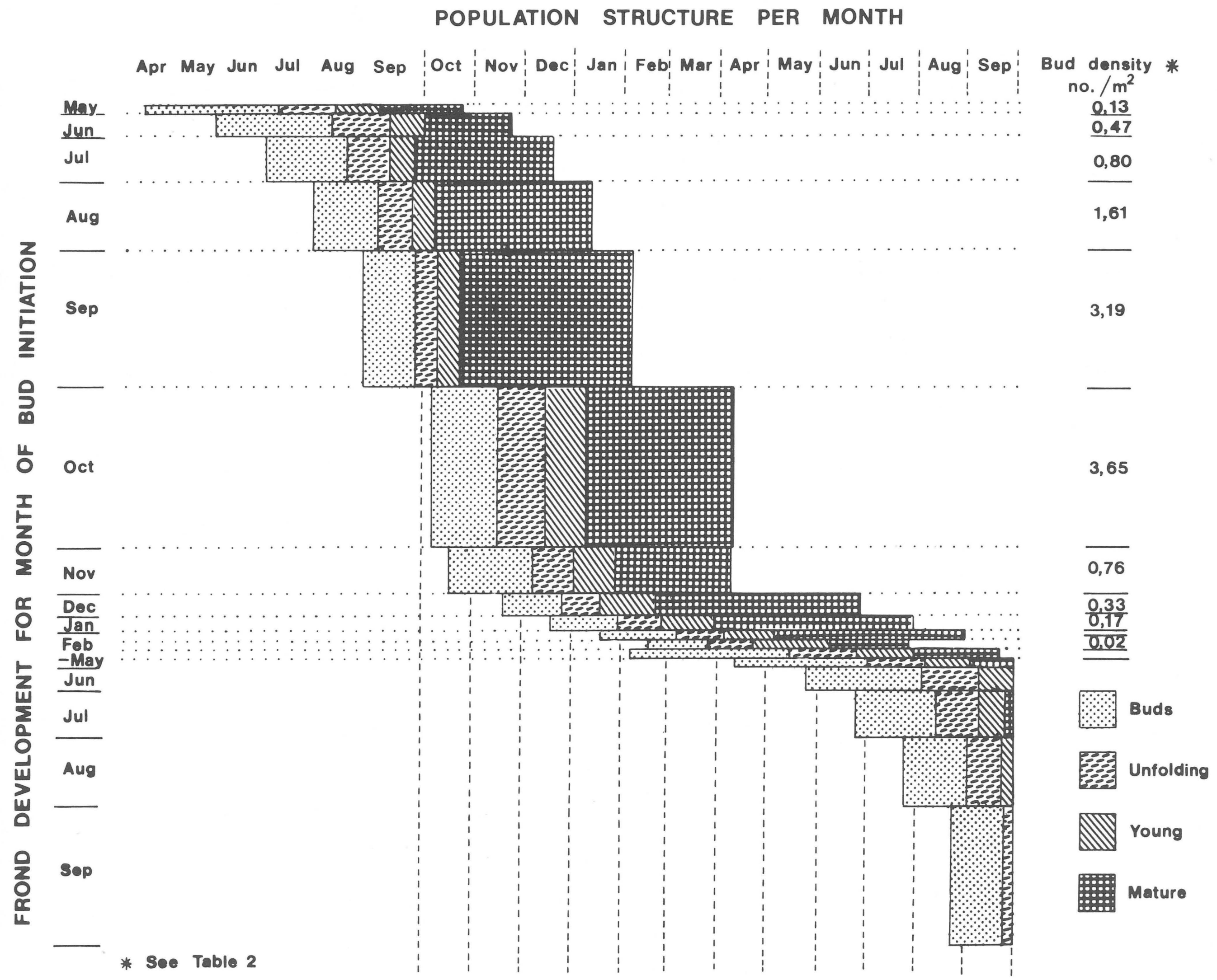

Figure 8 Model of seasonal change in *Rumohra adiantiformis* population structure due to different rates of frond development and numbers of buds initiated. The horizontal zones show the development rate of fronds through different stages, which varies according to the month of bud initiation and the month during which the frond develops through a particular stage. The depth of these zones indicates the number of buds which has developed during the particular month. The vertical zones indicate the ratio of frond stages occurring in the forest during a particular month. Note the large proportion of mature fronds during November–March, and the many immature fronds during July–September.

fronds. The differences are due to the lower densities of blocks 2, 4, 7 and 8, and no relationship is evident between initial density and effect of treatment.

Treatment effects on frond size

Thirty-four months after initiation of treatment we calculated a significant decline ($P < 0{,}01$) in mature frond size with increased frequency of harvesting all mature fronds (Table 4). Monthly harvesting reduced frond size to 24% of controls and 5-monthly harvesting reduced frond size to 51% of the controls. Several fronds in monthly plots were smaller than the standard used for utilizable fronds and were therefore not included in this calculation. Compared with size categories used by the contractor (S.J. Milton, pers. comm. 1985), mature fronds on control plots were large (> 350 mm lamina length), those on plots harvested 5-monthly were of medium size (250–350 mm) and those on plots harvested monthly were small (< 250 mm). Reduced size was associated with malformed lamina and leaflets.

Discussion

Fern population structure is determined by site, frond stand density and season. Observations in the study area and along monitoring transects in the Knysna area suggest that the fern grows densely on moist, well-drained sites, such as near ridge tops or hill crests on southern slopes, and lower down on the slopes close to but well above the streams, on both northern and southern slopes. The fern occurs extensively on the moist, well-drained aolian sands of the Harkerville and Kaffirkop areas. The fern was absent from shallow soils with shallow, fluctuating water table on underlying clays. Dense fern stands are usually associated with a sparse to absent shrub understorey of *Trichocladus crinitus*, and a relatively open tree canopy. Site relationships were not part of this study. A clearer understanding of the effects of site conditions on frond density and growth rate is required.

The clumped pattern, more obvious in sparse fern stands, results from the growth of closely spaced fronds

Table 2 Effects of treatment on composition of the frond stages of *Rumohra adiantiformis* in the Groenkop forest since start of treatment in July 1982

(a) Summary of population structure (numbers m^{-2})

		Treatment								
		Control			5-monthly			Monthly		
		1983	1984	1985	1983	1984	1985	1983	1984	1985
Buds	Feb.	0,22	0,28	0,22	0,47	0,25	0,41	0,59	0,56	0,44
	Oct.	3,81	4,13	*	1,59	1,28	*	1,38	0,91	*
Young fronds	Feb.	0,56	0,44	0,31	0,63	0,78	0,44	0,97	1,00	0,34
	Oct.	1,03	0,41	*	1,25	1,25	*	1,94	1,78	*
Mature fronds	Feb.	3,94	3,63	3,00	1,22	1,88	2,13	0,63	0,78	0,63
	Oct.	0,38	0,44	*	1,13	0,56	*	1,16	0,09	*
Old fronds	Feb.	8,09	7,56	9,28	2,34	3,16	4,72	2,50	2,69	4,44
	Oct.	8,13	7,97	*	2,44	3,69	*	1,88	3,09	*

*Data not available. Plants were destroyed for chemical analyses

(b) Analyses of variance (numbers per 4-m^2 plot)

	Buds (October)			Mature fronds (February)		
Source of variation	*Df*	*MS*	*F*-value	*Df*	*MS*	*F*-value
Treatments	2	618,40	32,69**	2	717,88	64,88**
Control vs. treatments	1	1225,44	64,77**	1	1278,06	115,14**
5-monthly vs. monthly	1	11,28	0,60ns	1	157,69	14,21**
Years	1	4,69	0,25ns	2	3,17	0,29ns
Replications	7	53,71	2,84*	7	90,84	8,18**
Error	37	18,92	–	60	11,10	–

$^{*}P < 0{,}05$; $^{**}P < 0{,}01$; ns not significant

Table 3 Total number of fronds utilized from the treated plots in Groenkop forest

	Treatment					
	5-monthly			Monthly		
		Fronds harvested			Fronds harvested	
Harvesting period	Harvest cycles	/year	/harvest	Harvest cycles	/year	/harvest
July 1982–June 1983	3	263	87,7	12	433	36,1
July 1983–June 1984	2	94	47,0	12	270	22,5
July 1984–June 1985	3	114	38,0	12	140	11,7

Table 4 Effects of cycles of harvesting all mature fronds of *Rumohra adiantiformis* on size of mature fronds in the Groenkop forest, after 3 years of treatment

(a) Frond number (n), average frond length ($\bar{x}$) and coefficient of variation ($s/\bar{x}$)

	Picking cycle								
	Control			5-monthly			1-monthly		
Replication	n	$\bar{x}$ (mm)	$s/\bar{x}$ (%)	n	$\bar{x}$ (mm)	$s/\bar{x}$ (%)	n	$\bar{x}$ (mm)	$s/\bar{x}$ (%)
1	19	396	17,9	12	264	26,5	6	278	42,8
2	8	366	26,2	6	205	38,0	6	157	25,5
3	13	466	28,5	12	350	29,4	7	259	47,5
4	10	495	26,3	7	340	25,3	5	238	30,7
5	11	413	19,1	9	423	12,3	10	174	17,8
6	13	495	18,8	7	331	25,1	6	215	35,8
7	13	442	24,7	6	355	40,3	4	278	33,1
8	10	376	39,6	7	239	29,3	4	115	27,0

(b) Analysis of variance of treatment effects on frond lamina length

Source of variation	*Df*	*SS*	*MS*	*F*-value
Treatments	2	188602	94301	47,52**
Control vs. picking	1		149280	75,25**
5-monthly vs. 1-monthly	1		39320	19,82**
Replications	7	51825	7403	3,73*
Error	14	27781	1984	

*$P < 0,05$; **$P < 0,01$

(c) Effects of treatments on average frond size

		Frond lamina					
		Length		Width			
Treatment	No. of fronds	$\bar{x}$ (mm)	$s/\bar{x}$ (%)	$\bar{x}$ (mm)	$s/\bar{x}$ (%)	Average frond lamina area (m^2)	Frond lamina area as % of area for fronds from controls (%)
Control	97	433	26,2	498	28,0	0,2156	100,00
5-monthly	66	317	33,5	350	31,2	0,1110	51,45
1-monthly	48	213	42,9	238	41,1	0,0507	23,50

from the creeping rhizome. No information is available on the contribution of sexual reproduction to the structure of the population. S.J. Milton (pers. comm. 1985) suggested that differential survival of gametophytes or young sporophytes, possibly in response to drainage or moisture differences, could cause a patchy distribution of the fern. In dense fern this clumping is not obvious due to several rhizomes growing across one another. Fronds within a fern stand appear to be all of uniform height, but in fact show a considerable range in height. This could be attributed to either immature plants or suppressed individuals. The ratio of frond stages changed with season. This should be considered during investigation of harvesting effects.

The time and numbers of bud formation and bud growth rate to maturity varied seasonally. Numbers of new buds, growth rate of fronds and frond stalk length (i.e. production of good quality fronds at high density) were greatest for buds which initiated during June–September (winter to spring). Watt (1945) recorded a relationship between the emergence of young fronds of *Pteridium aquilinum* and soil moisture. We suggest that moisture availability may affect the development of buds and ultimately frond size. Firstly, Thornthwaith potential evapotranspiration is generally low, i.e. indicating a moisture surplus, during the July–October period when most buds form, compared to a moisture deficit during summer when few buds form and most fronds mature. Secondly, during 1984/85 the usual high number of buds formed, but numbers of mature fronds peaked at a lower level and took longer to reach this level. This may be related to the period of exceptionally low rainfall of May–August 1984.

The period from April to December must be considered as sensitive to harvesting. During this time buds initiate and grow to maturity, i.e. immature, soft fronds dominate the population.

Harvest cycles applied in the Groenkop plots showed marked effects on fern population structure (Table 2; Figure 7), and on annual production (Table 3) and size of mature fronds (Table 4). Watt (1943) attributed a similar reduction in frond size and density with regular cutting of

Pteridium aquilinum fronds to the depletion of nutrients. We suggest that poor development and lowered production of fronds resulted from depletion of the stored resources of the plant. Evidence for this includes malformed fronds and reduction in numbers of mature fronds in harvested plots. Other observations also point to a depletion of resources. The sharp increase in mature frond numbers on control plots until reaching the peak and the gradual decrease afterwards (Figure 7b) may have caused the drop in growth rate (13,6 weeks in October, Table 1) after the initial rapid maturation (8,5 weeks in September) and longer mature stage. Treated plots show a similar pattern, but with much lower peaks. The very short mature stage of March–June buds (mature during June–October) is probably caused by the many new buds developing during June–October and which would utilize most of the available resources in the plant.

The depletion of resources possibly relates to the high content of potassium and the internal cycling of both phosphorus and potassium in *Rumohra* (Fitts *et al.* 1983; Geldenhuys & van der Merwe 1986). Potassium content declined from 3,05% dry mass in buds, 1,42% in mature fronds, 0,73% in old fronds to 0,32% in dead fronds of control plants during September. Phosphorus levels decline from 0,10% in buds to 0,03% in dead fronds. Soil phosphorus content in the southern Cape soils is deficient ($<$ 10 ppm), and potassium content is low to reasonable (50–200 ppm) (T.A. Robertson, pers. comm. 1986). Regular harvesting of all mature fronds would deplete the potassium and phosphorus resources in the plant. Harder *et al.* (1965), Larcher (1975) and Theron (1985) summarize the role of potassium in the plant. Potassium accumulates in young tissue and sites of intense metabolism. A high potassium status promotes a high water content and turgor (hydration) which prevents transpiration losses and wilting. Potassium activates enzyme systems involved in metabolism of both carbohydrates and nitrogen. Potassium deficiency limits photosynthetic rate, increases respiration rate, causes a decrease in total leaf surface area and reduces leaf life. Deficiency symptoms are first noticeable in older leaves, i.e. scorched and curly leaf tips and edges, due to the inhibition of protein synthesis and the accumulation of toxins.

The frequency and intensity of harvesting should allow for fronds to grow through to the old stage to recycle some of the nutrients. All mature fronds were harvested in the treatment plots, but only 50–70% of mature fronds in the contract area are normally harvested. The initial harvest cycle in the contract area was close to the monthly treatment, but was increased to the average period for fronds to mature, i.e. 16 weeks. It is a matter of concern that even with a 5-month cycle, frond size and numbers decreased with continued picking. Milton & Moll (1987) studied individual plants in the Harkerville forest. On average each plant produced 1,26 fronds per annum. Limitation of harvest intensity to a maximum of 50% of mature fronds would allow at least one frond to continue with production of carbohydrates and recycling of essential nutrients to the growing tip.

Different and changing attitudes of contractors, different contract values in relation to potential productivity of harvested areas, and conservation requirements make monitoring essential for the guidance and control of harvesting activities. Our sampling method for determining fern population structure and for monitoring in the contract area could be used by the authorities to monitor more objectively the effects of harvesting on the *Rumohra* growing stock. The method provides a basis for issuing permits for fern harvesting, and for decisions on extension of permits of private forest owners. We suggest that permits should be withdrawn when fern condition (density and size) have deteriorated. The positive correlation between frond stalk length and frond size (lamina area), and the effect of harvest frequency (at high intensity) on frond size, suggest that frond stalk length could reflect the past harvest intensity or the production potential of the site. We therefore suggest that a particular area should be withdrawn from harvesting if the average frond stalk length is less than 400 mm, i.e. average lamina length of healthy mature fronds of 250 mm.

The interactive approach between researchers and managers which we followed in this study was both informative and productive. We had periodic discussions with both the managers and the contractor which have led to continuous improvement of the management system and to closer investigation of relevant questions. The initial harvest cycle was increased from 5 to 8 weeks, then to 16 weeks and eventually to 25 weeks as more information became available. Harvest intensity decreased after the interim release to the contractor of monitoring results which indicated that harvest intensity exceeded the stated limits. Maintenance of fern quality required that the fern be harvested at lower intensity and over longer cycles. A larger harvest area was therefore released to enable the contractor to maintain production.

Current harvesting of fern was conducted on the basis of short-term contracts. The area available for harvesting in the southern Cape is approximately 20 000 ha. The fern industry employs approximately 150 unskilled labourers and a number of trained supervisors, and has developed suitable infrastructure (storage facilities, transport) and markets. Export expenses require that the amounts of fern harvested during a particular period should allow the filling of suitable containers to capacity. Short-tern contracts do not allow costly developments unless the maximum numbers of fern fronds could be harvested. The effects of such excessive harvesting may not be observed timeously. We therefore suggest that long-term contracts should be considered to enhance the conservation of the resource by both the contractor and the forest owner.

The study indicated the importance of frond harvesting at suitably long intervals and low intensity to sustain production. Frond production from the forest is further limited by variable weather conditions, and by the relatively small forest area suitable for fern growth. Future expansion of this lucrative industry lies in the cultivation of the fern under controlled nursery conditions. The results suggest lightly shaded conditions, moist well-drained sites and addition of potassium and phosphorus for maintenance of frond quality. Initial studies conducted by private growers (R.M. Botha, pers. comm. 1985) indicate a reduced shelf life for nursery-grown fronds. The importance of potassium was, however, not considered and research in this direction should be pursued.

Recommendations resulting from this study can be summarized as follows:

(1) The harvest cycle should be increased to at least 25 weeks with a reduced harvest during the low-crop season (March–June) and withholding of harvest when immature fronds dominate (July–October). A single annual harvest during summer is preferred. In all cases harvest intensity should be restricted to 50% of mature fronds.
(2) An area should be withdrawn from harvesting if the average frond stalk length is less than 400 mm, i.e. representing average lamina length of healthy mature fronds of 250 mm.
(3) Permanent plots should be established throughout the harvested areas to gather information on the spatial

variation in growth of individual plants, and harvest effects on tree regeneration and soil compaction.

(4) Additional experiments should investigate the effects on the fern of longer harvest cycles at different intensities and during different seasons. Rates of recovery of deteriorated fern stands should be determined.

(5) Efforts to develop techniques for production of fern fronds under controlled nursery conditions should be encouraged. Investigations should consider shading, irrigation and application of potassium and phosphorus fertilizers.

(6) Nature conservation authorities should use the suggested monitoring survey methods to assess and control harvesting of fern in private forests as a basis for the permit system.

(7) Long-term contracts should form the basis of fern harvesting in natural areas.

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